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[54] **CUMULATIVE FATIGUE LIFE INDICATOR**

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[52] **U.S. Cl.** **73/91**

[51] **Int. Cl.** **G01n 3/32**

[58] **Field of Search** ..... 73/91, 88.5 R, 71.2, 73/90

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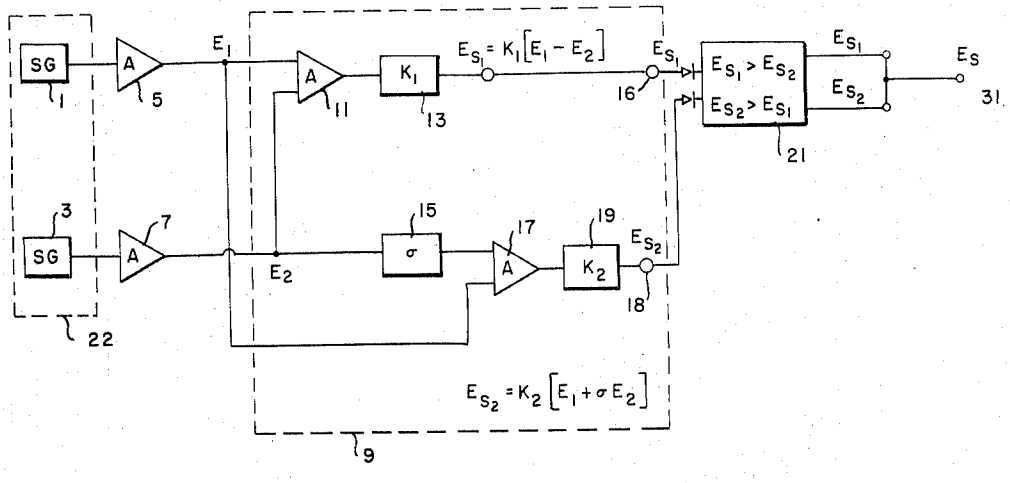
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[57] **ABSTRACT**

The purpose of this invention is accumulation and display of information indicative of expended and remaining fatigue life of a test specimen or pressure vessel. Strain-gauge output signals are amplified by a dual channel conditioning circuit. The dual channel bipolar strain signals are then used to compute the alternating stress range absolute value on a continuous basis. Voltage signals proportional to the alternating stress are then presented to a counter which registers the individual accumulated stress cycles with reference to the total allowable cycles in thousandths of counts and provides a usage factor indicating cumulative fatigue damage and remaining fatigue life.

5 Claims, 2 Drawing Figures



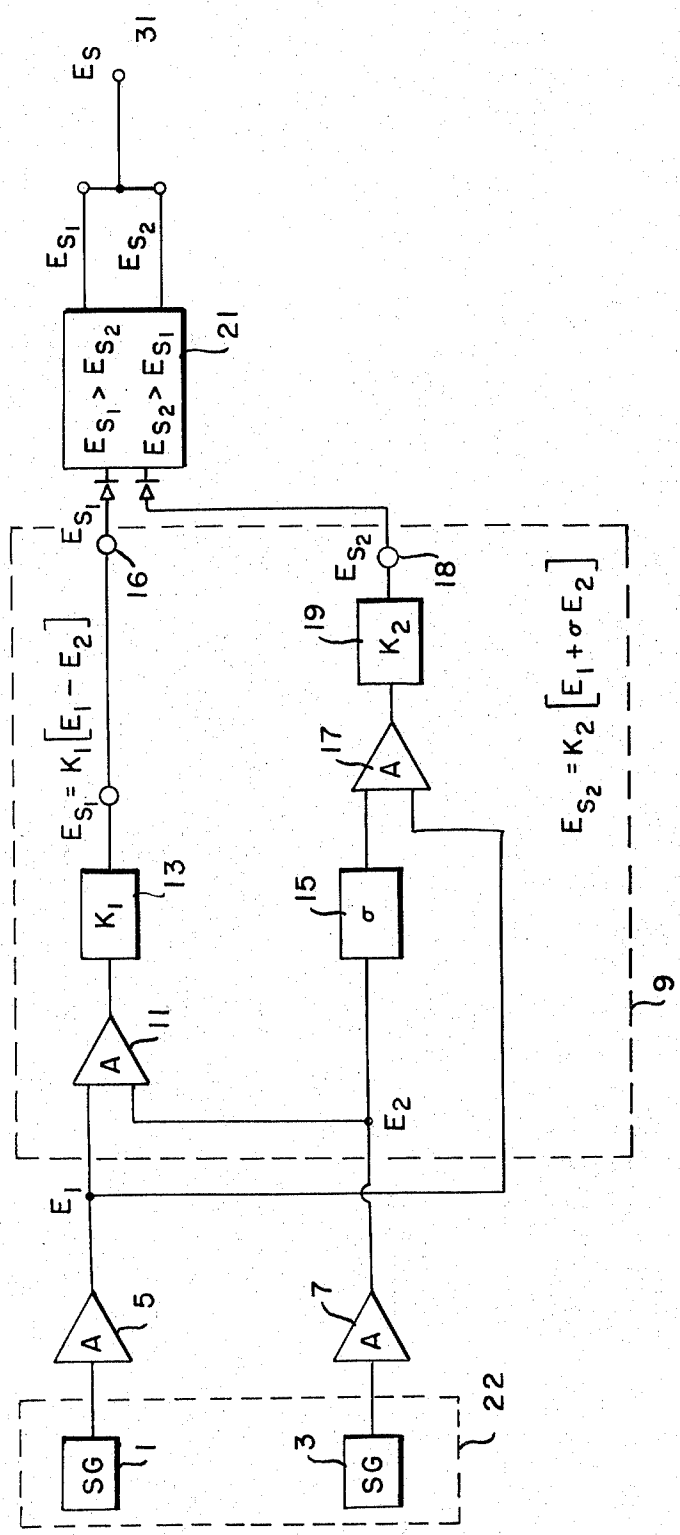
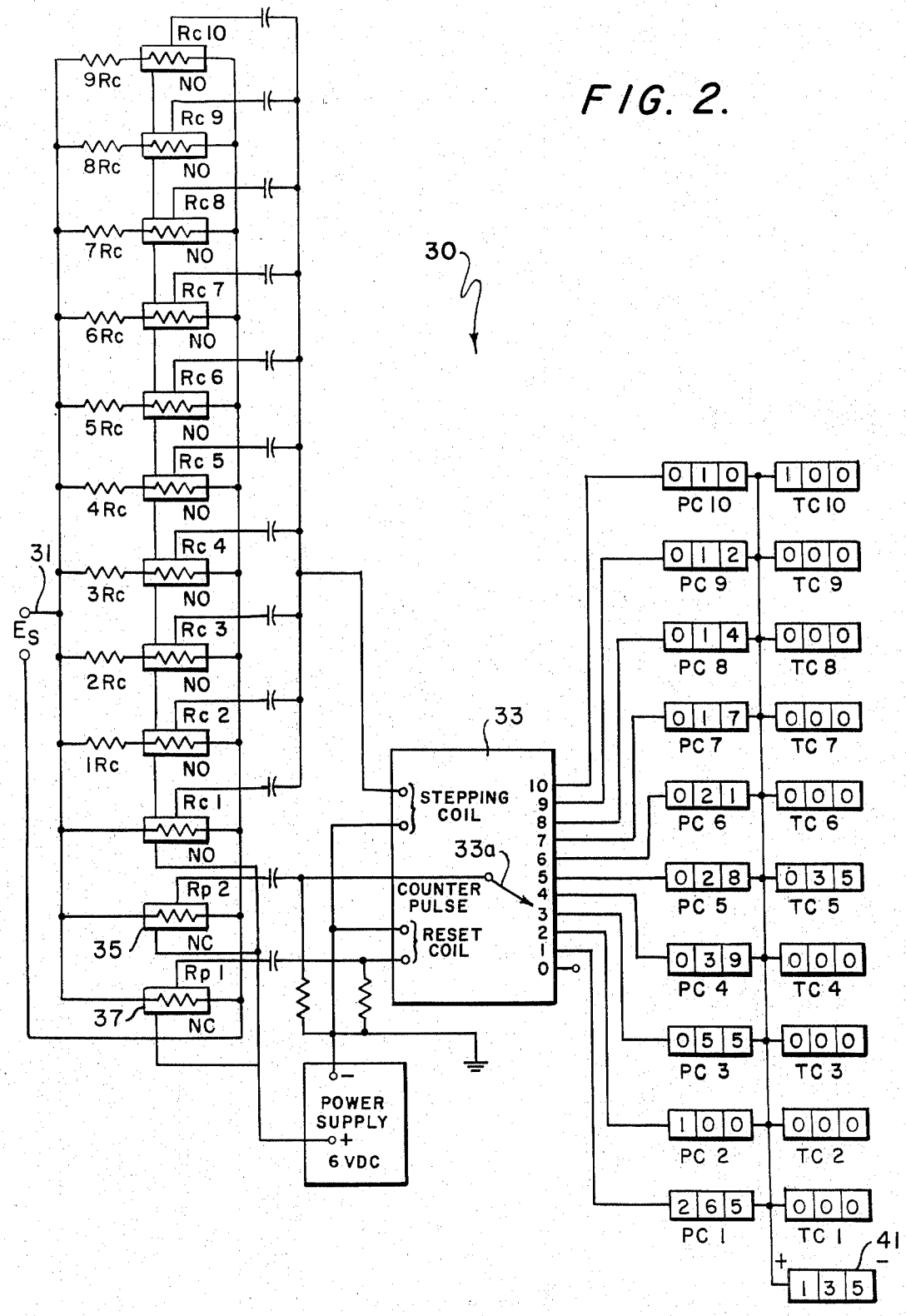

E_S
31
E_S1
E_S2
E_S1 > E_S2
E_S2 > E_S1
21
E_S1
16
E_S2
18
19
K_2
17
A
E_S1 = K_1[E_1 - E_2]
E_S2 = K_2[E_1 + σE_2]
K_1
13
15
σ
A
11
E_2
9
E_1
A
5
A
7
22
SG
1
3
SG

FIG. 1.

FIG. 2.


Rc 10
9Rc
NO
Rc 9
8Rc
NO
Rc 8
7Rc
NO
Rc 7
6Rc
NO
Rc 6
5Rc
NO
Rc 5
4Rc
NO
Rc 4
3Rc
NO
Rc 3
2Rc
NO
Rc 2
1Rc
NO
Rc 1
NO
Rp 2
NC
Rp 1
NC
31
Es
35
37
30
33
33a
STEPPING COIL
COUNTER PULSE
RESET COIL
10
9
8
7
6
5
4
3
2
1
0
POWER SUPPLY
+
6 VDC
PC 10
0 1 0
TC 10
1 0 0
PC 9
0 1 2
TC 9
0 0 0
PC 8
0 1 4
TC 8
0 0 0
PC 7
0 1 7
TC 7
0 0 0
PC 6
0 2 1
TC 6
0 0 0
PC 5
0 2 8
TC 5
0 3 5
PC 4
0 3 9
TC 4
0 0 0
PC 3
0 5 5
TC 3
0 0 0
PC 2
1 0 0
TC 2
0 0 0
PC 1
2 6 5
TC 1
0 0 0
41
+
-
1 3 5

CUMULATIVE FATIGUE LIFE INDICATOR

The invention described herein may be manufactured and used by or for the Government of the United States of America for Governmental purposes without the payment of any royalties thereon or therefor.

This invention relates to the measurable strain imposed upon a structure and the fatigue accumulated by the structure under the strain. The purpose of the invention is to accumulate and display information indicative of the expended and remaining fatigue life of a structure. In the past, structures such as pressure vessels, have been utilized without maintaining operational data indicative of the fatigue of the structure and its remaining life. Although stress cycle fatigue curves can be accurately determined making this type of monitoring feasible, there is no device in existence which is capable of accumulating this data in terms of a signal and storing and visually displaying this information so that the remaining useful life of the device can be quickly and accurately determined.

SUMMARY OF THE INVENTION

Strain data is obtained from standard strain-gauges mounted on a test specimen and producing cyclical bipolar (E_1 and E_2) signals indicative of maximum bipolar stress. The signals are amplified and combined according to a predetermined mathematical relationship to yield two new signals, called the alternating stress range, representing one-half the principle stress difference (designated ES_1, ES_2). The absolute value of one of these stress signals ES_1 or ES_2 will always be greater than the absolute value of the other, ES_2 or ES_1. The rectified signals, ES_1 and ES_2 are then placed in parallel and a signal output is derived representing the larger of the cyclical alternating stress values, ES_1 and ES_2.

The larger signal of ES_1 and ES_2 is inputted to a voltage divider network whose output is proportional to the absolute value of the alternating stress range. The voltage divider is tied into a relay tree, with each relay responsive to a one volt increment of input signal. The number of relays actuated will then be equal to the magnitude of the signal, (i.e., a 4 volt signal actuates relays **1, 2, 3,** and **4**) and the relay output will be a number of pulses equal to the voltage magnitude input. Pulses on the relays are routed to a rotary stepper which steps the rotary switch to a numbered position corresponding to the input signal magnitude. As the alternating stress signal amplitude decays, a second pulse is produced which is routed to the step rotary switch connecting the pulse to an appropriate counter. In this way, a count is registered at the appropriate stress level by a display counter for each alternating stress cycle.

A number of counters are provided equal to the maximum alternating stress voltage and equal to the number of pulse increments. Each counter registers the ratio *ni*/NI where ni is equal to the number of expended cycles for operation at the particular stress level and NI is equal to the number of cycles to failure at the same level. The counters are calibrated to equal one one-thousandth of the total allowable cycles of allowable fatigue for the specimen at the respective stress level for each counter. In addition, an additional counter connected to the outputs of each of the counters corresponding to a respective input level accumulates the total number of counts.

Accordingly, it is one object of this invention to accumulate and display information indicative of expended and remaining fatigue life of a structure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows in block diagram the system for developing signals proportional to strain and combining the signals to produce bipolar signals indicative of the alternating stress differences ES_1 and ES_2;

FIG. **2** shows the portion of the device responsive to the larger of the values of ES_1 or ES_2 and including a voltage divider and relay bank connected to a stepping switch for channeling a counting pulse to an appropriate counter corresponding to the cyclical alternating stress signal amplitude.

DESCRIPTION OF THE INVENTION

A dual channel strain-gauge signal amplification circuit is shown in FIG. **1** as having two bipolar strain-gauges **1** and **3** mounted on a structure **2.** Each of the strain-gauge signals is amplified by bipolar amplifiers **5** and **7** which have bipolar outputs E_1 and E_2 respectively.

The portion of the system shown within dashed box **9** receives the bipolar strain signals E_1 and E_2 and produces a signal equal to the alternating stress range (one-half the difference of the principle stresses) on a continuous basis. The computations involved are:

$$ES_1 = K_1 [E_1 - E_2]$$

$$ES_2 = K_2 [E_1 + \sigma E_2]$$

where K_1 is the modulus of elasticity, divided by two times the quantity **1** plus Poisson's ratio, and

K_2 is the modulus of elasticity divided by two times the quantity **1** minus the square of Poisson's ratio.

E_1 is the algebraic value of the strain in a direction of maximum stress on the surface of the structure.

E_2 is the algebraic value of the strain in the direction of minimum stress on the surface of the structure, and

σ is Poisson's ratio.

Cyclical alternating stress signals ES_1 is produced by connecting signals E_1 and E_2 to differential amplifier **11** and connecting the output of amplifier **11** to amplifier **13** having an amplification factor of K_1.

Similarly, ES_2 is produced by amplifying signal E_2 by an amplification factor σ, adding E_1 to σE_2 through amplifiers **17** and **15** and amplifying the output of amplifier **17** by an amplification factor K_2.

The signals ES_1 and ES_2 at terminals **16** and **18** respectively, are connected to a discriminator **21** which compares signals ES_1 and ES_2 and whose output is the larger of the absolute values of signals ES_1 and ES_2.

The absolute value of the cyclical stress signal ES_1 or ES_2 is always greater than the absolute value of the respective other signal ES_1 or ES_2. In this embodiment, ES has a maximum value of **10** volts corresponding to maximum cyclical stress.

Referring now to FIG. **2,** the logic system **30** for visually displaying the stress levels represented by the signal output of discriminator **21** is shown. Input terminal **31** is connected to the output of discriminator **21,** and connected to a voltage dividing network comprising relays RC1–RC10. In this embodiment, the relays are 1 volt relays, and each 1 volt relay is connected in series to a respective resistance, RC10 connected to 9RC, RC9 connected to 8RC, . . . RC2 connected to 1RC, and RC1 connected directly to terminal **31,** with each

resistance having a value so the number of relays triggered by an input signal ES will be equal to the highest integral value of the signal ES at terminal **31.** This may be explained by the following example. If the maximum signal ES were to be 10 volts, and with smaller signals representing smaller magnitudes of strain, the voltage divider network may be set up so that only RC1 is triggered by a one volt magnitude signal ES, RC1 and RC2 are triggered by a signal magnitude $3 > ES > 2$, RC3, RC2, and RC1 are triggered by signal $4 > ES > 3$, . . . and all relays, RC10, RC9, RC8, RC7, RC6, RC5, RC4, RC3, RC2, and RC1 are triggered by a signal $ES = 10V$. The pulses produced by the relays are connected to stepping switch **33** which advances rotary switch **33***a* to the contact corresponding to the magnitude of the signal ES and in response to the corresponding number of pulses received. As shown in FIG. **2,** a signal $5V > ES > 4V$ will produce a total of four pulses with each relay RC1, RC2, RC3, and RC4 producing a single pulse each and will advance the rotary switch **33***a* to position **4.**

As signal ES decays, corresponding to a decrease in the cyclical strain, 1 volt normally closed (NC) relay **35,** opened by the signal pulse ES now closes as signal ES drops back towards **0.** At closing, relay **35** sends a pulse through rotary switch **33***a* and contact **4.** As the alternating stress signal ES decays further, NC relay **37,** opened by signal ES, now closes sending a reset pulse to the reset coil of stepper switch **33** and resetting rotary switch **33***a* back to **0** to await the next cyclical stress signal.

Each of the counters PC1 through PC10 are connected to a respective terminal (**0–10**) of stepping switch **33** and each advances **1** count for each pulse received through its terminal from relay **37.** Each counter (PC1–PC10) is preset to produce an output pulse for every x pulses received from stepping switch **33.** The output of each counter (PC1-PC10) is connected to a display counter TC1-TC10 respectively, which is incremented for each pulse output of its respective counter PC1–PC10. By picking x to be equal to one one-thousandths of the total allowable stress cycles, the counters (TC1–TC10) will register accumulated cycles of stress per total allowable cycles in thousandths of counts ($F_{10} = n_{10}/N_{10}$; $F_9 = n_9/N_9$; . . . $F_2 = n_2/N_2$; $F_1 = n_1/N_1$). This counting activity occurs at all of the **10** stress levels represented by cyclical stress magnitudes represented by a signal of 1 to 10 volts.

In addition, counter **41** connected in parallel to the outputs of PC1–PC10 is incremented one count for each increment in the count of any one of the counters TC1–TC10. The output of counter **41** is a usage factor $U = (F_1 + F_2 + \ldots F_9 + F_{10})$ equal to the sum of the individual counts in each of the counters (PC1–PC10) and equal to the sum of the individual ratios of accumulated cycles to total allowable cycles, in thousandths of allowable cycles at each stress level and indicates cumulative fatigue damage and remaining fatigue life.

We claim:

1. A system for storing and indicating cumulative fatigue life of a structure comprising:

a structure to be measured for cumulative fatigue;

strain gauge means attached to the structure along the principal stress axes for sensing cyclical strain;

means connected to said strain gauge means and responsive thereto for generating alternating stress signals ES_1 and ES_2 wherein:

$ES_1 = K_1$ [Emax-Emin]

$ES_2 = K_2$[Emax + σ Emin]; and where,

K_1 is the modulus of elasticity of the material divided by $2(1+\sigma)$;

K_2 is the modulus of elasticity of the material divided by $2(1-\sigma^2)$;

Emax is the strain signal produced in response to strain in the direction of the maximum stress on the structure;

Emin is the strain signal produced in response to strain in the direction of the minimum stress on the structure;

σ is the Poisson's ratio; and further including:

means connected to receive said cyclical stress signals, and responsive thereto for indicating the number of stress cycles at discrete levels of strain.

2. The system of claim **1** wherein:

said means for indicating the number of accumulated stress cycles includes means for discriminating between ES_1 and ES_2 and selecting the larger of ES_1 and ES_2; and

said means for indicating includes means responsive to said larger signal for storing and indicating the total cumulative stress cycles at each discrete level of stress corresponding to each discrete stress signal generated.

3. The system of claim **2** wherein:

said means for storing and indicating the total cumulative stress cycles at each discrete level includes;

means to generate a plurality of pulses corresponding to the larger of the signals ES_1 or ES_2;

a first plurality of counters, each counter of said first plurality of counters corresponding to a respective discrete signal stress level;

means responsive to said pulses for connecting said pulse generating means to a respective counter of said first plurality of counters corresponding to the signal stress level ES_1 or ES_2;

said respective counter being incremented in response to a pulse generated by said pulse generator;

said incrementing pulse being generated in response to said stress signal ES_1 or ES_2 dropping below a predetermined threshold at the end of each strain cycle.

4. The system of claim **3** wherein:

said counters are each calibrated to generate a single output pulse in response to x pulses received where x is equal to one one-thousandths of the allowable stress cycles at the stress level corresponding to said respective counters.

5. The system of claim **4** including:

a second plurality of counters; wherein:

each said counter of said first plurality of counters connected to said pulse generator responsive to a stress signal ES_1 or ES_2 has its output connected to a corresponding counter of said second plurality of counters and incrementing said corresponding counter of said second plurality of counters in response to receiving x increments from said pulse generator; and including:

a usage counter;

all said first plurality of counters being connected to said usage counter for indicating the cumulative usage factor;

said counter for indicating cumulative usage factor being incremented for each pulse output for each of said first plurality of counters and indicating the cumulative fatigue damage.

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